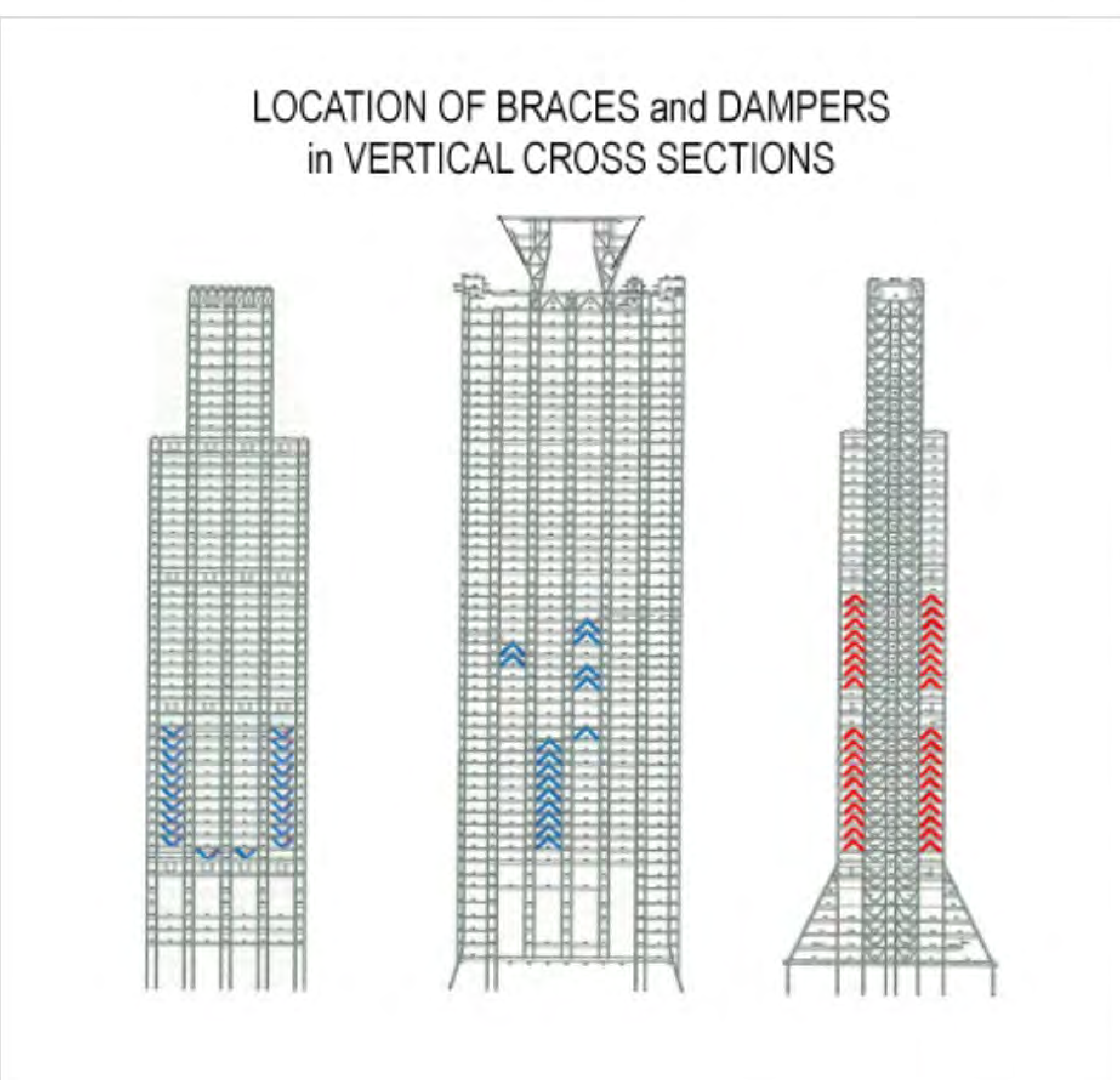
55-Story Tall Building – Before and After Earthquake Retrofit

What if the shaking from an earthquake was irrelevant because all our buildings were safe from collapse, and they could keep us safe inside them? That's one of the goals earthquake engineers are trying to accomplish. USGS earthquake engineer Mehmet Çelebi and several other colleagues in other organizations recently studied the "before" and "after" of a 55-story tall building in Osaka, Japan that was subjected to two real earthquakes, once before a seismic retrofit and again after the retrofit. This project offerred a rare opportunity to study the retrofit "before" and "after" of a tall building shaken by two distant earthquakes. The scientists wanted to know how the engineering improvements had changed the response of the building to potentially-damaging shaking that is caused by large distant earthquakes.

The 55-story tall building in Osaka, Japan, and a map with a red star at the location of the building. (Photo by Mehmet Çelebi, USGS)

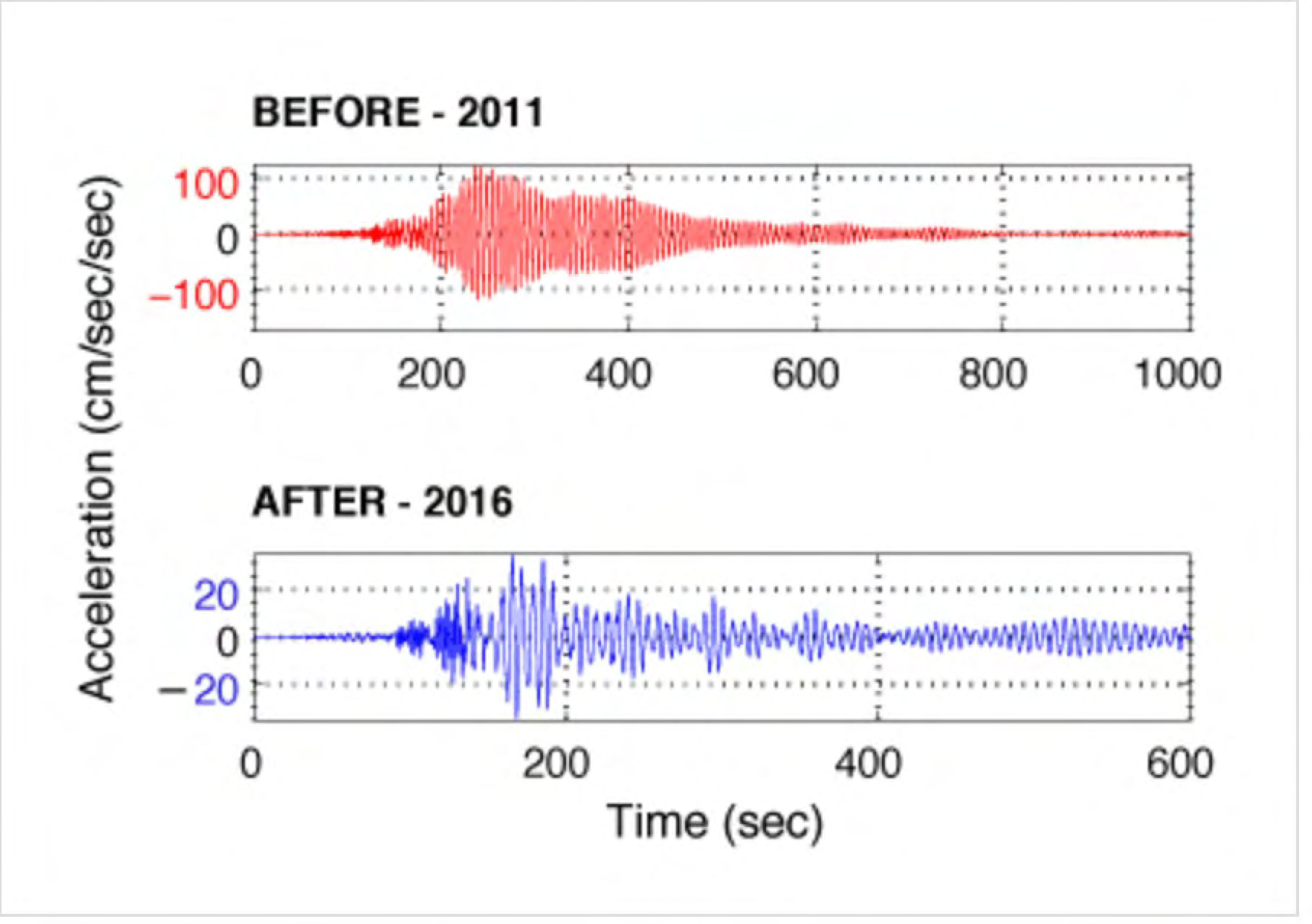
When an earthquake occurs, energy is radiated out in all directions through the earth's crust as seismic waves that we feel as shaking. The shaking behavior includes fast shaking motions like a toddler shaking a rattle, as well as slower shaking that's more like an ocean swell. The fast-shaking (called short-period) energy is dominant near the earthquake location and tends to die out before the waves travel very far, but the slow-shaking (long-period) energy is able to travel very far in the earth's crust before it dies out. Tall buildings are affected more by the long-period energy, and shorter buildings are affected more by the short-period energy.



A schematic drawing showing the locations of the braces (blue) and dampers (red) installed in the building for the retrofit. The left drawing is the front "panel" of the building (see photo above); the middle drawing is the middle section of the building, and the right drawing is the view of the side of the building.

Both earthquakes that shook the building were far away, and the long-period waves had a significant effect on the building. The M9.0 Tohoku earthquake on March 11, 2011 (767 km/476 mi away) was recorded on several seismic instruments inside the building, and the recordings showed that the building had undergone severe and extended shaking that had possibly threatened the integrity of the structure. A retrofit was clearly called for. The retrofit was intended to dampen the shaking of the building so that the contents and people inside would not shake as much. 140 dampers and 114 buckling restrained bracers (BRBs) were installed in the building.

Dampers are similar to a suspension in a car that makes the ride more comfortable by decreasing the vibrations. Their function in a building is to decrease the severity of shaking in the building. When vibrations are decreased in a building, there is less chance of damage. A BRB is intended to prevent motion between the floors of the building by providing extra rigidity, and at the same time, decrease the shaking by allowing the ends to yield, or buckle, which increases the damping capability of the building. BRB's are now widely used in new and retrofitted buildings. (See the photos below.)



The recorded shaking of the building from two distant earthquakes before and after the retrofit. The seismic instrument that recorded these two events was on the 52nd floor oriented in the N-S direction. Note that the acceleration before was about 5 times larger than after.

Japan is in a dynamic tectonic setting, and as such, experiences frequent earthquakes. On April 24, 2016 the M7.3 Kumamoto earthquake (478 km/297 mi away) shook the building, and again the shaking was recorded on the seismic instruments inside. The good news was that indeed the severity of the shaking was lessened by the retrofit, however there are indications that the building can still experience significant shaking. This knowledge can be used for the engineering and retrofits of similar tall buildings in the future. Currently, in the United States, we are not aware of any buildings taller than 35 stories that have been retrofitted.

-written by Lisa Wald, U.S. Geological Survey

Two of the braces as seen from inside the building. (Photo by Mehmet Çelebi, USGS)

Two of the dampers as seen from inside the building. (Photo by Mehmet Çelebi, USGS)

For More Information

- [Earthquake Monitoring of Structures]
- Mehmet Çelebi, Toshihide Kashima, S. Farid Ghahari, Shin Koyama, Ertuğrul Taciroğlu, and Izuru Okawa (2017) Before and After Retrofit Behavior and Performance of a 55-Story Tall Building Inferred from Distant Earthquake and Ambient Vibration Data. Earthquake Spectra: November 2017, Vol. 33, No. 4, pp. 1599-1626.

The Scientist Behind the Science

Mehmet Çelebi inside the display room on the roof of the 73-story Costeneras Tower in Santiago, Chile. (Photo courtesy of Mehmet Çelebi, USGS)

Mehmet Çelebi has been a USGS earthquake engineer for 34 years. He got interested in earthquakes when as a child his hometown was shaken by an earthquake, and the whole family slept in tents for a couple of weeks. He taught earthquake engineering and structural dynamics at METU (Middle East Technical University) in Ankara from 1969 to 1977, and also was a co-founder of the METU EERC (Earthquake Engineering Research Center). He enjoys spending time with his 5 grandchildren!